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DEPARTMENT OF
EMPLOYMENT AND PRODUCTIVITY

FUMES FROM WELDING AND FLAME CUTTING

Report on the Shipbuilding
and Ship-repairing Industry

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FOREWORD

The following report has been produced as the result of a survey by a small team led by Mr. S. J. Silk of the Industrial Hygiene Section of the Inspectorate, into the toxic hazards of welding and flame cutting in the shipbuilding and ship-repairing industry in North-East England. It is evident from reading this report that, generally, insufficient attention has been paid to the dangers of toxic fumes emitted during various welding and flame cutting processes. It calls for greatly improved standards of fume control including, where necessary, efficient local exhaust ventilation. In some confined spaces, where this is not possible, the wearing of suitable breathing apparatus is considered essential.

Although the survey was limited to the shipbuilding and ship-repairing industry, the results and recommendations warrant circulation to industry in general, since they may have an application to any undertaking where welding or flame cutting is carried on. Managements would be well advised to study the results of the survey and, where appropriate, put the recommendations of the report into effect immediately.

W. J. C. PLUMBE

HM Chief Inspector of Factories

Introduction

The increasing use in the shipbuilding and ship-repairing industry of steel plate primed with a zinc-rich coating has made the emission of zinc fume at the high temperatures involved in welding and flame cutting a hazard of some proportion calling for a quantitative assessment in the different conditions under which it was evolved. While it was recognised that zinc fume would be one of the major hazards, the opportunity was taken to investigate as thoroughly as possible, all the toxic gases and fumes known to be evolved during the welding and flame cutting of steel, not only that primed with a zinc-rich protection, but also with red oxide of iron. Unprotected mild steel, stainless steel and alloyed steel were covered where these were encountered during the survey. In addition, argon arc welding of aluminium was investigated.

A period of six weeks between October 1967 and February 1968 was spent, mainly in the Tyne, Wear and Tees areas, investigating the toxic hazards arising from welding and flame cutting. The investigation sought not only to establish what toxic hazards were produced but also to indicate, in a practical fashion, how working conditions could be improved to meet the requirements of Regulation 53 of the Shipbuilding and Ship-repairing Regulations 1960, (see page 15).

Types of welding and flame cutting

All known types of welding and flame cutting employed in the shipbuilding and ship-repairing industry were assessed wherever they were met. It will be noted in the table of results (Appendix A) that some processes are listed more frequently than others but the aim was to keep the ratio approximately in proportion to their actual use in the industry.

The following types of welding and cutting were met during the survey:

(1) open arc welding,
(2) gas shielded welding including carbon dioxide shielded welding of steel and argon arc welding of aluminium,
(3) submerged arc welding,
(4) oxy-acetylene flame cutting,
(5) oxy-propane flame cutting.

In addition, and where appropriate, the type of flux coating on the welding rods was noted. In order to summarise the results, these were divided according to the information received into two groups, rutile and basic, although many welding rods had different trade names with no doubt some variation in composition. The main purpose in correlating the flux coating on the welding rods was to check fluoride fume evolved during welding. Fluorides are the main toxic constituent of the coating and are understood to be present in higher proportions in basic-coated electrodes. Other types of welding electrodes included mild steel wire, copper-coated steel wire, stainless steel wire for welding stainless steel and aluminium wire for argon arc welding of aluminium.

Toxic Hazards

The toxic hazards arising during welding and flame cutting can be divided into two categories, i.e. gases and fumes.

Gases

The gases determined during the survey were those which, from our own experience, were known to be present during welding and flame cutting of metals and also those reported by other investigators but not previously met by ourselves, for example sulphur dioxide. Some gases, for example hydrogen fluoride, if present, would only arise when flux-covered electrodes were used during the operation.

The following gases are those which were investigated during the survey:

carbon monoxide
carbon dioxide
nitrogen dioxide
ozone
hydrogen fluoride
sulphur dioxide

Fumes

A fume can be defined as particulate matter of submicron particle size which arises from the volatilisation of metals or salts when heated to sufficiently high temperature. Where the steel has a zinc-rich coating copious zinc fumes are evolved because of the low melting point of this metal in relation to the very high temperatures attained during welding and flame cutting. Where the fume is a result of the volatilisation of a metal it rapidly oxidises in the atmosphere forming oxides of the metal in a very finely divided form.

The fumes evolved during welding and flame cutting will depend, then, on the composition of metal being welded or flame cut, including its surface coating, and on the composition of the electrodes. Thus we can expect fluoride fumes where flux-covered electrodes are used. The following fumes were investigated where appropriate to the situation:

(1) zinc
(2) iron
(3) cobalt, nickel and manganese (where present in stainless and alloyed steels)
(4) copper and lead (where copper-covered electrodes were used)
(5) fluorides

Titanium dioxide is a major constituent of rutile electrodes, and in consequence titanium would be expected to be a constituent of the fume. Titanium has a very low toxic rating compared with the other fumes being investigated and is said to be physiologically inert. Therefore the determination of titanium during the survey was omitted as the recommendations to control the other toxic hazards could be expected to control any possible hazard from the titanium present in the fume.

Welding and flame cutting sites

It was felt that although much useful information might be derived from an atmospheric survey of the general conditions under which welding and flame cutting was taking place, the results would be of far greater value and a much better impact would be made by trying to relate the results to the actual conditions under which work was in progress. In consequence it was decided to divide the welding sites into four categories:

(1) open air
(2) open workshop
(3) semi-confined spaces
(4) confined spaces

A certain amount of difficulty was bound to be experienced in differentiating between categories (3) and (4) assessment therefore needed to be made by the survey team on the spot during the period in which sampling took place. As a guide, cabins having no direct openings to the outside atmosphere were considered to be semi-confined spaces; such situations as double bottoms and side tanks were considered to be confined spaces.

Ventilation

In the summary of results the type of ventilation at the site of welding of flame cutting has been noted. It was decided not to try to make a quantitative assessment of the standard of ventilation whether natural, forced, or local exhaust, because of the large number of variable factors that were likely to affect it. In very large open workshops where fabrication of various structures took place, the general ventilation could generally be classed as good, although even at these sites the weather conditions played a large part in determining the natural air movement.

In confined and semi-confined spaces the provision of local exhaust ventilation has been recorded when it was reasonably close to the welding point. Where the exhaust inlet has been provided in the space but was not close to the weld, this has been recorded as forced general ventilation. In order to assess the effect of local exhaust ventilation on the exposure of the welder to toxic gases and fumes it was originally intended to record the distance of the exhaust inlet from the weld or cut and possibly the rate of exhaust. However, as the work or cut progressed the distance of the exhaust inlet from the welding point became greater because there was no continual adjustment to provide a constant distance, any attempt to assess this factor had to be abandoned.

Sampling sites and methods of sampling

The sampling sites studied can be summarised into four main categories:

(1) in the plume of fume rising from the welding or cutting operation
(2) the general atmosphere in the working area
(3) breathing level in the vicinity of the welding mask
(4) the atmosphere actually breathed by the welder behind the welding shield. In the determination of fume, a personal sampling instrument, known as a respirometer and worn by the welder, was used although in some cases this prevented the normal positioning of the shield. Where the determination of a toxic gas was required the sampling probe inlet was placed at the side of the welding shield from where the atmosphere breathed by the welder was taken.

The main object of sampling in the plume of fume was to try to detect and determine trace amounts of toxic contaminants which may have been present in the fume. These traces would have been too diluted to give a positive reading by the time the fume reached breathing level or the general atmosphere of the working area.

The gases were determined in the main by calibrated detector tubes or by simple chemical methods as described in 'Methods for the Detection of Toxic Substances in Air' published by HMSO, and a new method for the determination of ozone in the presence of nitrous fumes which is awaiting publication.

The particulate fumes were first filtered on suitable media from recorded volumes of air, before being evaluated in the laboratory by well established chemical and physical methods.

Evaluation of the Results

Toxic Gases

***Carbon monoxide**
(*Threshold limit value 50 ppm*)

Open arc welding
Eleven samples taken in the fume varied from 2-120 ppm averaging 38 ppm. Forty-four samples taken at breathing level varied from 0-100 ppm (the latter figure in a confined space), averaging 15 ppm. The only occasion on which the TLV* (threshold limit value) was exceeded was in a confined space where conditions were very poor and local exhaust ventilation, although available, was not provided because of a misunderstanding.

Argon arc welding
Of the five samples taken in the fume and at breathing level only one registered any carbon monoxide, and that only 2 ppm.

Carbon dioxide shielded arc welding
Presumably due to reduction of some of the carbon dioxide during welding, five samples taken in the fume varied between 200-500 ppm, averaging 278 ppm. Two samples taken at breathing level showed concentration of 15 ppm.

Submerged arc welding
Five samples taken directly above the flux covering the arc varied between 300-1,000 ppm, averaging 538 ppm. Four samples taken at breathing level showed concentrations of 0-30 ppm, averaging 11 ppm.

Oxy-acetylene and oxy-propane flame cutting
Of the four samples taken, the highest was 40 ppm in the fume and the lowest 9 ppm at breathing level. The average of the three samples taken at breathing level was 18 ppm.

Conclusions
There was no significant hazard from carbon monoxide in the conditions found during the survey, although on one ocasion, during open arc welding in a confined space when no exhaust ventilation was provided because of a misunderstanding, the concentration rose to 100 ppm. Carbon dioxide shielded arc welding and submerged arc welding showed high concentrations of carbon monoxide in the fume, but only an average of 11-15 ppm at breathing level. Although these types of welding appeared to take place mainly in open shop conditions, a significant hazard might arise in confined spaces with poor ventilation.

***Carbon dioxide**
(*Threshold limit value 5,000 ppm*)

Open arc welding
There was no significant difference in concentrations of carbon dioxide in samples taken in the fume and at breathing level. The average concentration from 43 samples was about 1,000 ppm. On the occasion cited in the section on carbon monoxide when sampling took place in a confined space without local exhaust ventilation, the concentration of carbon dioxide reached 6,000 ppm.

Argon arc welding
Two samples taken in the fume averaged 600 ppm, and three samples taken at breathing level averaged 330 ppm.

Carbon dioxide shielded arc welding
Sampling close to the weld was likely to give high and variable concentrations and on one occasion this reached 60,000 ppm. Two samples taken at breathing level recorded concentrations of 1,700 ppm and 7,000 ppm. There was no occasion during the survey when carbon dioxide shielded welding took place in a confined space. If this had been necessary, a significant carbon dioxide hazard might have been encountered because the provision of local exhaust ventilation would have interfered with the carbon dioxide shield and so spoilt the quality of the weld. Under such circumstances the provision of air-line breathing apparatus would be the only effective safeguard. In our general experience there is little hazard in well-ventilated open air and open workshop conditions.

Submerged arc welding
Three samples taken in the fume averaged only 400 ppm.

Oxy-acetylene and oxy-propane flame cutting
In confined and semi-confined conditions four samples ranged from 700 ppm to 3,000 ppm, averaging 1,900 ppm.

Conclusions
Except for the comments made about carbon dioxide shielded arc welding (see above) no significant hazards were apparent from carbon dioxide. Precautions that need to be taken in semi-confined and confined spaces to eliminate hazards from more toxic gases and fumes would deal adequately with carbon dioxide.

Nitrogen Dioxide
†(*Ceiling value 5 ppm.*)

Open arc welding
Twenty-one samples taken in the plume of fume ranged from 0·6 ppm-10 ppm, averaging 3·7 ppm.

**The average concentration in air which must not be exceeded over an eight hour working day (Threshold limit values. TDN 2/69 free on application from HM Factory Inspectorate).*

†The concentration in air which should not be exceeded at any time (TDN 2/69).

Fifty-three samples taken at breathing level in all the different conditions ranged from 0-20 ppm, averaging 3·5 ppm. It is significant however that 19 samples taken in confined and semi-confined spaces ranged from 4-20 ppm, averaging 7·4 ppm, while in open air and open shop conditions few of the 34 samples taken were more than 2 ppm while the average was around 1 ppm.

In a number of situations, samples were taken inside and outside the operator's welding shield. These indicated that there was about four times the concentration of nitrogen dioxide outside and in front of the welding shield than there was behind it. In well ventilated open air and open shop conditions, where the gases and fumes could rapidly disperse, maintenance of this factor could be expected. However in semi-confined and confined spaces, particularly where no ventilation is provided, this factor would rapidly diminish and equilibrium would be attained.

Argon arc and carbon dioxide shielded arc welding

These classes of welding were generally only found in open workshops although in one case the site was recorded as a confined space because welding took place inside a fabricated section in the open workshop.

There was little difference in the nitrogen dioxide concentrations measured in the plume of fume and at breathing level. Out of 19 samples taken only three reached the TLV of 5 ppm and the overall average was 1·6 ppm. On two occasions, when concentrations of 4 ppm and 5 ppm were registered at breathing level outside the welding shield, the respective concentrations inside the shield were 1 ppm and 0·5 ppm. The welding shield, therefore, afforded some measure of protection in well ventilated open shop and open air conditions.

Submerged arc welding

Of the five samples taken, four were in the fume. The maximum concentration of nitrous fumes recorded was 1·5 ppm and the average 0·5 ppm.

Oxy-acetylene and oxy-propane flame cutting

In one confined space where oxy-acetylene flame cutting was in progress, concentrations of 12 ppm from two samples were recorded in the plume of fume, with an average of about 10 ppm from three samples taken four feet above the weld and an average of 9 ppm from three samples taken at breathing level.

In another confined space, where oxy-propane flame cutting was being carried out, three samples taken at breathing level averaged just over 8 ppm.

Conclusions

The results of the samples taken of nitrogen dioxide showed the need for better general ventilation in addition to efficient local exhaust ventilation in confined and semi-confined spaces. In well ventilated open shop and open air conditions there was no significant hazard and the operator's welding shield provided an added measure of protection.

Ozone

(*Threshold limit value 0·1 ppm*)

Open arc welding

A total of 15 samples were taken for ozone in connection with open arc welding of mild steel (uncoated, red oxide coated, and zinc coated) both in the fume and at breathing level. Ozone was not detected on any occasion although the sampling sites varied from open air to confined spaces. The sensitivity of the method was such that concentrations would certainly be less than half the TLV.

Ozone was detected, however, during the open arc welding of manganese steel using low hydrogen basic-coated electrodes. At one site, in a large open workshop, concentrations of 0·12 ppm and 0·15 ppm were recorded in the fume. At another similar site with no local exhaust ventilation, 0·2 ppm was recorded nine inches above the weld. When local exhaust ventilation was provided ozone could not be detected.

Argon arc welding

Six samples were taken during argon arc welding of stainless steel. At one site, in open workshop conditions, up to 1·0 ppm of ozone was recorded in the fume although ozone could not be detected at the operator's breathing level. At another open site a similar concentration of 0·9 ppm was recorded in the fume. At yet another site, 0·9 ppm was recorded at breathing level in a semi-confined space.

Variable quantities of ozone were also detected during argon arc welding of aluminium. At one site 0·2 ppm and 0·3 ppm were found in the fume and at another less than 0·05 ppm was found at breathing level. A further site revealed an average of 0·8 ppm at breathing level from three samples.

When samples in the fume, at breathing level and inside the welding shield, were taken in an open workshop while mild steel was being welded with an argon and carbon dioxide cover, a steep gradation in concentrations was recorded, for example 1·6 ppm in the fume, 0·7 ppm at breathing level. Fumes were not detected inside the welding shield.

Carbon dioxide shielded arc welding

As with argon arc welding, the concentrations of ozone recorded were very variable. At one site only one of two samples in the fume just reached the TLV while at another 1·7 ppm was detected in the fume. Ozone could not be detected inside the welding shield.

Submerged arc welding and oxy-acetylene flame cutting

Sufficient samples were not taken to give a categoric assessment of the ozone hazard. Neither a sample taken in the fume during submerged arc welding nor at breathing level during oxy-acetylene flame cutting indicated the presence of ozone.

Conclusions

Only argon and carbon dioxide gas shielded welding appeared to produce significant quantities of ozone although very small amounts were found in the fume produced when open arc welding of manganese steel took place.

In well ventilated open workshop and open air conditions, there did not appear to be any significant hazard to the operator behind the welding shield. Where argon arc and carbon dioxide shielded welding are required in confined and semi-confined spaces, it will probably be necessary for all persons employed in those spaces to use air-line breathing equipment to protect them from excessive ozone concentrations.

Sulphur dioxide

(*Threshold limit value 5 ppm*).
This gas could not be detected in 18 samples taken in the fume and at breathing level at every category of site and type of welding. The sensitivity of the method was such that the concentration of sulphur dioxide would be less than one tenth of the TLV.

Hydrogen fluoride

(*Threshold limit value 3 ppm.*)
The possibility of the formation of hydrogen fluoride was investigated as fluorides were known to be present in the flux coating on some electrodes, particularly the basic ones. Of the four samples taken, one was in the fume from submerged arc welding and hydrogen fluoride could not be detected. From the method sensitivity the concentration could be presumed to be less than one tenth of the threshold limit value.

Toxic fumes

Iron oxide fume

(*Threshold limit value 10 milligrams/cu metre.*)

Open arc welding

The results of the sampling are best summarised in two tables. Table 1 shows a comparison of iron oxide fume concentrations between confined and semi-confined spaces on one hand and open air and open workshop conditions on the other.

Table 2 analyses further the conditions in confined and semi-confined spaces by comparing the effect of forced general ventilation and natural ventilation at these sites. Out of 27 confined and semi-confined spaces where sampling took place, only one was considered to have local exhaust ventilation and the remainder were almost equally divided between the forced and natural ventilation categories.

Other types of welding and flame cutting

Twenty samples for iron oxide fume were taken at sites employing other types of welding and flame cutting. On three occasions the TLV was exceeded and fairly consistent figures around the TLV were found in connection with personal respirometer samples taken at oxy-propane cutting in semi-confined spaces. There appears to be no reason to suppose that conditions are not similar to those in connection with open arc welding at comparable sites.

Table 1

Sampling site	Sampling positions	Number of samples	Number of times TLV exceeded	Recorded minimum and maximum concentrations of iron oxide fume in milligrams/cu metre	Recorded average concentrations of iron oxide fume in milligrams/cu metre
Confined and semi-confined spaces	General atmosphere	28	5	0·1-56·0	8·5
	Personal respirometer samples	32	9	0·1-60·0	13·2
Open workshop and open air sites	General atmosphere	20	—	0·1-3·3	0·9
	Personal respirometer samples	7	—	0·1-5·0	2·6

Table 2

Sampling position	Type of ventilation	Number of samples	Number of times TLV exceeded	Recorded minimum and maximum concentrations of iron oxide fume in milligrams/cu metre	Recorded average concentrations of iron oxide fume in milligrams/cu metre
General atmosphere	Natural ventilation	14	6	0·5-56·0	15·1
	Forced general ventilation	13	—	0·1-7·5	1·7
Personal respirometer samples	Natural ventilation	13	4	3·0-60·0	21·8
	Forced general ventilation	12	4	0.1-29.0	9·6

Conclusions

While forced general ventilation is generally successful in keeping average iron oxide fume concentrations down to well below the TLV in the general atmosphere of confined and semi-confined spaces, and to about the TLV in connection with the personal exposure of the welder, efficient local exhaust ventilation is without doubt necessary in order to obtain satisfactory working conditions.

Zinc oxide fume

(*Threshold limit value 5 milligrams/cu metres*)

Although the problem of zinc oxide fume was known to be one of the number of hazards existing where welding and flame cutting of zinc-coated steel plate was carried out, no specific attempt was made to highlight it and it was investigated only where it was met during the survey team's visits to shipyards. There was one exception to this procedure; at one site (Appendix A, No. 36), the effect of the provision of local exhaust ventilation compared with forced general ventilation was investigated.

Open arc welding

Open arc welding was employed on nearly all the sites where zinc-coated steel plate was in use. Sampling was carried out in 33 open arc welding sites and of these 14 were concerned with zinc-coated steel plate. At one shipyard no zinc-coated steel plate was used at all.

Quite a number of samples taken at sites not using zinc-coated plate were analysed for zinc at the same time as for iron. Most of these, of course, only showed traces of zinc except where they were in fairly close proximity to sites where welding of zinc-coated steel plate was in progress. It was noticeable that in cabins below deck, where ventilation was generally speaking poor, there was often a background of welding fume over considerable areas of the ship.

Where welding of zinc-coated steel plate was in progress, the concentrations of zinc oxide fume at different sites was extremely variable. This was only to be expected where an extremely high temperature was applied to a low melting point metal (zinc) resulting in copious emissions of visible white zinc oxide fume. Many open arc welding sites in confined and semi-confined spaces had some form of forced ventilation but even the movement of the sampling head a matter of inches could produce widely varying results. Comparisons of concentrations of zinc oxide fume found in the general atmosphere and at breathing level gives only a general picture, although the personal respirometer samples should give a true indication of the exposure of the welder. It will be noted from Appendix B that concentrations as high as 86, 271, and 720 milligrams/cu metre were found in two semi-confined spaces.

The personal respirometer samples showing the exposure of the welders in confined and semi-confined spaces are probably worth highlighting in table 3. The effect of good local exhaust ventilation compared with forced general ventilation is worthwhile noting at site 36 a confined space (Table 4 and Appendix A).

Other types of welding and flame cutting

Very little welding in connection with zinc-coated steel plate using the other listed categories of welding and flame cutting was seen during the survey, but there is no doubt that the conclusions arrived at above on open arc welding would apply equally to this section.

Table 3

Welding sites	Number of samples	Number of times TLV exceeded	Minimum and maximum concentrations of zinc oxide fume in milligrams/cu metre	Average concentrations of zinc oxide fume in milligrams/cu metre
Confined spaces	11	5	2·8-35·0	13·3
Semi-confined spaces	8	3	0-47·0	9·2

Table 4

Type of ventilation	Sampling position	Number of samples	Minimum and maximum concentrations of zinc oxide fume in milligrams/cu metre	Average concentrations of zinc oxide fume in milligrams/cu metre
Forced general ventilation	General atmosphere	3	11·5-30·2	22·2
	Breathing level	3	8·6-60·0	36·5
	Personal respirometer samples	5	4·0-55·0	20·9
Local exhaust ventilation	General atmosphere	1	—	5·0
	Breathing level	1	—	2·7
	Personal respirometer samples	2	—	Not detected

Conclusions

Where welding and flame cutting of zinc-coated steel takes place in confined and semi-confined spaces the provision of efficient local exhaust ventilation is essential.

While the hazard in open air and open workshop sites is of a lower category, local exhaust ventilation is recommended to take the zinc oxide fume away from the breathing zone of the welder in order to provide completely satisfactory conditions.

Inorganic fluoride fume

(*Threshold limit value 2·5 milligrams/cu metre: as fluoride*

The general atmosphere and personal respirometer samples taken where the rutile type flux-covered electrodes were used did not differ appreciably from those where the basic flux-covered electrodes were in use.

Where the rutile type flux-covered electrodes were used 14 samples taken in the general atmosphere averaged 0·7 milligrams fluoride fume/cu metre. However if the two samples at one semi-confined space with natural ventilation, which were the only ones to exceed the threshold limit value with 3·0 and 3·2 milligrams/cu metre, were not taken into account, the remaining 12 samples averaged only 0·25 milligrams/cu metre. Parallel personal respirometer samples, of which there were 12, averaged 0·5 milligrams/cu metre with a maximum of 1·0 milligrams/cu metre.

Where basic flux-covered electrodes were used nine general atmosphere samples averaged 0·3 milligrams fluoride fume/cu metre with a maximum of 0·8 milligrams/cu metre. One personal respirometer sample showed a concentration of 0·8 milligrams/cu metre.

Conclusions

Under the conditions met during the survey, the fluoride fume hazard was not of any great significance. The provision of local exhaust ventilation in confined and semi-confined spaces, necessarily required to deal with other toxic hazards, would prevent any build up of fluoride fume and eliminate any hazard from this source.

Other metal fumes

Manganese

(*Ceiling value 5 milligrams/cu metre*)

Of the five samples, including two personal respirometer samples, taken during welding of stainless steel, four were less than 0·1 milligrams/cu metre and the fifth 0·2 milligrams/cu metre. Six samples were taken during welding of manganese steels and of these five general atmosphere samples averaged 0·2 milligrams/cu metre of manganese fume and the other, a personal respirometer sample, showed a concentration of 1·7 milligrams/cu metre.

Nickel

(*Threshold limit value 1·0 milligrams/cu metre*)

Of the five samples, including two personal respirometer samples, taken during welding of stainless steels, four were less than 0·1 milligrams/cu metre and the fifth 0·1 milligrams/cu metre.

Cobalt

(*Threshold limit value 0·5 milligrams/cu metre*)

All four samples, including two personal respirometer samples, taken during the welding of stainless steels were less than 0·1 milligrams/cu metre.

Copper

(*Threshold limit value of the fume 0·1 milligrams/cu metre*)

Out of 11 samples taken in the general atmosphere and at breathing level around the welding shield, where copper-coated wire was used for electrodes, four exceeded the threshold limit value and on one occasion reached 1·4 milligrams/cu metre.

Lead

(*Threshold limit value 0·2 milligrams/cu metre*)

There was occasional evidence of the presence of lead in the fume emitted when copper-coated wire electrodes were used. Although the hazard on the whole does not appear to be of great significance, a more detailed investigation to find the source of the lead and eliminate it would be desirable. The precautions required to deal with the hazard from copper fume would eliminate any lead fume hazard at the same time. Lead fume was also detected in the general atmosphere on one occasion when open arc welding of steel plate protected with a multi-coat paint system was in progress.

Conclusions

There appeared to be no significant hazard from manganese, cobalt and nickel fumes during welding of manganese and stainless steels.

Where copper-coated steel wire electrodes were used there was evidence of significant emission of copper fumes which, at least in confined spaces, would require the provision of efficient local exhaust ventilation. At the same time, there was some evidence of lead fume but the precautions required for dealing with copper fume would deal adequately with the lead hazard. On one occasion there was some evidence of lead fume during welding of steel coated with a multi-paint system. This indicated the need to ensure that effective local exhaust ventilation is provided for such work where there is a possibility of heating metal coated with a lead-based paint.

Summary and Recommendations

Open air and open workshop conditions

Generally speaking there were no consistently significant hazards at open air and open workshop sites. However there was occasional evidence that high concentrations of zinc fume during open arc welding of zinc-coated steel plate, of ozone during argon arc welding of aluminium, and of copper fume during the use of copper-coated steel wire electrodes existed at breathing level in the area of the welding shield. This makes the provision of local exhaust ventilation desirable in order to provide entirely satisfactory working conditions at some of these sites.

Confined and semi-confined spaces

The survey shows that conditions were generally not satisfactory in confined and semi-confined spaces. There is ample evidence, in the section evaluating the results, that much better control of zinc oxide fume, iron oxide fume, and nitrous fumes is necessary. Where forced general ventilation is provided there is certainly some improvement in conditions as shown in the second table in the section on iron oxide fume. However, the exhaust inlets providing the forced ventilation were seldom close enough to the welding operation to be really effective. The only way to achieve a satisfactory standard of control is to provide means for moving the the exhaust inlet with the weld so that the welding fumes are removed to the outside atmosphere instead of entering the working space.

Many of the cabins below deck, which were classed as semi-confined spaces, in which welding was taking place, were poorly ventilated and there was often a background of welding fume. Efficient local exhaust ventilation would eliminate the background of welding fume and provide the necessary improvement in general ventilation although there was also a need for fresh-air inlets to provide the necessary make up for the air being exhausted from the space.

In small confined spaces, such as some double bottom sites, the provision of local exhaust ventilation is virtually impossible because of the lack of space. In such situations it is essential that the welder wears suitable breathing apparatus, for example of the air-line type.

It may, on other occasions, be necessary to ensure that all persons involved in work in confined spaces should be protected by suitable breathing apparatus if the background of welding fume cannot be sufficiently controlled below the threshold limit value by forced general ventilation.

Substitution of protective zinc-rich coatings on steel plate

There is no doubt that substitution of the zinc-rich coating on steel plate where it is used by a less toxic and less volatile coating, for example red oxide of iron if it is technically possible, would considerably decrease the fume hazard during welding. It would not, however, eliminate the need for local exhaust ventilation in confined and semi-confined spaces. It was noted in one shipyard that zinc-coated plate brought into the yard was uncoated for two to three inches along the edges, thus enabling welding to take place without copious emission of zinc oxide fumes.

Supervision

At most shipyards there was generally the need for better supervision in order to improve the control of welding fumes in the working environment to the necessary higher standard. Full use was not always made of the exhaust fans available and there were difficulties in ensuring that they were always positioned to the best possible advantage. On other occasions sufficient exhaust fans were not available for welding sites where they were needed.

Industrial hygiene control

There is obviously scope for much better industrial hygiene control to ensure safe and satisfactory working conditions, particularly in confined and semi-confined spaces. To implement this it is recommended that a full-time Industrial Hygienist is employed by the industry in one area or alternatively by a large group of shipyards. He would be responsible for ensuring proper supervision of all the precautions including adequate ventilation and exhaust ventilation, where necessary. He would also ensure the regular monitoring of working atmospheres and personal exposures so that an adequate record could be built up.

It is realised that with some of the less frequently used types of welding and cutting some of the investigations made during this survey were perhaps less extensive than we could have wished and require more detailed investigation. We do not think, however, that our final summary and recommendations would be altered in any way.

Regulation 53

Shipbuilding and Ship-repairing Regulations, 1960

Where in connection with any process carried on on board, in or on the outside of a vessel or part of a vessel there is given off any dust or fume or other impurity of such a character and to such an extent as to be likely to be injurious to the persons employed, all practicable measures shall be taken to protect the persons employed against inhalation of the dust or fume or other impurity, and in particular, where practicable, exhaust appliances shall be provided and maintained, as near as possible to the point of origin of the dust or fume or other impurity, to protect such persons against such inhalation.

In the case of a shipyard the provisions of this Regulation shall, as respects the operations carried on on board, in or on the outside of a vessel or part of a vessel, be in substitution for the provisions of section 47 [now section 63 of the Factories Act 1961] of the principal Act (which relates to the removal of dust or fumes).

Appendix A: Full results of survey

Reference	Type of welding or cutting	Type of electrode	Material	Surface treatment	Situation	Ventilation	Carbon monoxide in ppm (TLV 50)			Carbon dioxide in ppm (TLV 5000)			Nitrogen dioxide in ppm (ceiling value 5)		
							In fume	Breathing level	Other samples	In fume	Breathing level	Other samples	In fume	Breathing level	Other samples
1	Open arc welding	Rutile type flux covered	Mild steel	Zinc sprayed	Ship. Confined space	Forced general ventilation	6 6 40	5 12					4·0 7·0	1·5 0·7	
2	Open arc welding	Rutile type flux covered	Mild steel	Zinc sprayed	Ship. Semi-confined space	Forced general ventilation		5 5			800			1·0 1·7	
3	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Confined space	Forced general ventilation		5			1000			1·0	
4	Argon shielded arc welding	Stainless steel wire	Stainless steel	None	Ship. Semi-confined space	Natural ventilation		Not detected			200			4·0	1·0 inside shield
5	Open arc welding	Rutile type flux covered	Mild steel	Zinc sprayed and painted	Ship. Semi-confined space	Forced general ventilation		5			800			2·0	0·7 inside shield
6	Argon shielded arc welding	Aluminium wire	Aluminium	None	Shed. Open space	Natural ventilation		<5			200			5·0	0·5 shield inside
7	Open arc welding	Rutile type flux covered	Mild steel	Zinc sprayed	Ship. Semi-confined space	Forced general ventilation		5	Not detected 5 mins. after welding ceased		500	800 5 mins after welding ceased	2·0 2·0 2·0	1·0	0·5 5 mins after and not detected 10 min. after welding ceased
8	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Semi-confined space	Forced general ventilation		5			1000		2·0 5·0	0·5	
9	Open arc welding	Rutile type flux covered	Mild steel	Galvanised	Shed. Open space	Natural ventilation		10			600		8·0	6·0	0·5 inside shield
10	Argon and carbon dioxide shielded arc welding	Copper-coated mild steel wire	Mild steel	None	Shed. Open space	Local exhaust ventilation		15			1700			0·6	
11	Open arc welding	Basic coated low hydrogen electrode	Mild steel	Red oxide painted	Shed. Open space	Natural ventilation	25	Not detected		2000			6·0	Not detected	
12	Argon shielded arc welding	Stainless steel wire	Stainless steel	None	Shed. Open space	Natural ventilation	Not detected			600			1·0 0·4	Not detected	
13	Argon and carbon dioxide shielded arc welding	Copper-coated mild steel wire	Mild steel	None	Shed. Open space	Natural ventilation							0·3 5·0		
14	Argon shielded arc welding	Aluminium wire	Aluminium	None	Shed. Confined space	Natural ventilation	Not detected			600			1·0 1·5		

Ozone in ppm (TLV 0·1)			Iron in mg./cu. m. (TLV 10)			Zinc in mg./cu. m. (TLV 5)			Other contaminants, where tested, listed with TLVs and units					
In fume	Breathing level	Other samples	General atmosphere	Breathing level	Personal respirometer	General atmosphere	Breathing level	Personal respirometer	Sulphur dioxide 5 ppm Hydrogen fluoride 3 ppm Aluminium No TLV mg./cu. m. Lead 0·2 mg./cu. m. Copper 0·1 mg./cu. m. Manganese (CV) 5 mg./cu. m. Nickel 1 mg. cu. m. Cobalt Tentative 0·1 mg./cu. m. Inorganic fluoride 2.5 mg./cu. m.	In fume	General atmosphere	Breathing level	Personal respirometer	Reference
Not detected	Not detected		2·1						Sulphur dioxide	Not detected				1
					Not detected			Not detected	Sulphur dioxide	Not detected				2
Not detected			1·5						Sulphur dioxide	Not detected				3
	0·9		0·7		5·5	<0·1		<0·1	Sulphur dioxide			Not detected		4
									Manganese		<0·1		0·2	
									Nickel		<0·1		0·1	
									Cobalt		<0·01		Not detected	
	Not detected		<0·1 0·4		5·0	86 271		11·0	Sulphur dioxide			Not detected		5
	<0·01		<0·1			2·0		<0·1						6
	Not detected		0·6		1·7	720		47	Sulphur dioxide			Not detected		7
	Not detected		7·5 0·4 different sampling points		0·2	1·1 0·2 different sampling points		Not detected	Sulphur dioxide			Not detected		8
									Hydrogen fluoride			Not detected		
									Inorganic fluoride		0·3 & Not detected		Not detected	
	Not detected		0·1 0·8	13·3	0·3	17·8 11·6	168	Not detected	Sulphur dioxide	Not detected				9
1·6	0·7	Not detected inside shield	1·3		6·7	Not detected		Not detected	Sulphur dioxide			Not detected		10
									Lead (different results from different sampling points)		<0·1 1·0		Not detected	
									Copper		0·02 1·4		0·03	
Not detected			1·9 (28·4 in fume)		0·1				Sulphur dioxide	Not detected				11
									Hydrogen fluoride	Not detected				
									Inorganic fluoride	42·0	<0·1 <0·1		0·8	
1·0 0·05 different sampling points	Not detected		<0·1 0·3		11·3				Sulphur dioxide	Not detected				12
									Manganese		<0·1 <0·1		<0·1	
									Nickel		<0·1 <0·1		<0·1	
									Cobalt		Not detected		Not detected	
0·9 0·05 different sampling points														13
0·2 0·3									Sulphur dioxide	Not detected				14
									Aluminium	3·1				

Appendix A (*continued*). **Full results of survey**

							Carbon monoxide in ppm (TLV 50)			**Carbon dioxide in ppm (TLV 5000)**			**Nitrogen dioxide in ppm (ceiling value 5)**		
Reference	**Type of welding or cutting**	**Type of electrode**	**Material**	**Surface treatment**	**Situation**	**Ventilation**	In fume	Breathing level	Other samples	In fume	Breathing level	Other samples	In fume	Breathing level	Other samples
15	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Confined space	Natural ventilation		10 20 25 30			1400 2000 2100 2200			4·0 4·0 5·0 8·0 10·0	
16	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Confined space	Natural ventilation		7 10 10 10 10			1500 1000 1000 1000 1000			4·0 4·0 6·0 4·0 3·0	
18	Submerged arc welding	Copper-coated mild steel wire	Mild steel	Red oxide painted	Shed. Open space	Natural ventilation	1000 750	15 30		500			Not detected		
19	Carbon dioxide shielded arc welding	Copper-coated steel wire	Special grade manganese steel	Red oxide painted	Shed. Open space	Natural ventilation	200 200			5500			0·3 <0·1		
20	Submerged arc welding	Copper-coated mild steel wire	Mild steel	Red oxide painted	Shed. Open space	Natural ventilation	340	Not detected	40 12″ above weld	300			Not detected		
21	Argon shielded arc welding	Aluminium wire	Aluminium	None	Shed. Open space	Natural ventilation		Not detected			500			4·0 5·0 0·7	
22	Submerged arc welding	Copper-coated steel wire	Special grade manganese steel	Red oxide painted	Shed. Open space	Natural ventilation	300	Not detected	50 12″ above weld	400			0·3		
23	Open arc welding	Basic coated low hydrogen electrode	Special grade manganese steel	Red oxide painted	Ship. Very large space	Forced general ventilation	120	7		600	400		1·5	0·7	
24	Open arc welding	Basic coated low hydrogen electrode	Special grade manganese steel	Red oxide painted	Ship. Very large space	(a) Local exhaust ventilation			Not detected 9″ above weld			300 9″ above weld			Not detected 9″ above weld
						(b) Natural ventilation			50 9″ above weld			1500 9″ above weld			5·0 9″ above weld
25	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Shed. Semi-confined space	Natural ventilation		20	6 inside shield		1200	5000 inside shield	4·0	1·5	0·8 5 ft above weld
26	Open arc welding	Basic coated low hydrogen electrode	Mild steel	Red oxide painted	Shed. Open space	Natural ventilation		10			1000			1·0	

Ozone in ppm (TLV 0·1)			Iron in mg./cu. m. (TLV 10)			Zinc in mg./cu. m. (TLV 5)			Other contaminants, where tested, listed with TLVs and units					
In fume	Breathing level	Other samples	General atmosphere	Breathing level	Personal respirometer	General atmosphere	Breathing level	Personal respirometer	Sulphur dioxide 5 ppm Hydrogen fluoride 3 ppm Aluminium No TLV mg./cu. m. Lead 0·2 mg./cu. m. Copper 0·1 mg./cu. m. Manganese (CV) 5 mg./cu. m. Nickel 1 mg./cu. m. Cobalt Tentative 0·1 mg./cu. m. Inorganic fluoride 2·5 mg./cu. m.	In fume	General atmosphere	Breathing level	Personal respirometer	Reference
														15
														16
Not detected			— (4·2 in fume)						Sulphur dioxide	Not detected				18
									Lead	1·4				
									Copper	0·3				
									Inorganic fluoride	8·3				
0·1 <0·1			6·2	10·0					Sulphur dioxide	Not detected				19
									Lead		0·1 <0·1	0·7		
									Copper		<0·1 0·5	0·8		
									Manganese		0·1 0·1	1·7		
									Hydrogen fluoride	Not detected				20
	0·9 0·6 0·9													21
														22
0·15 0·12			0·7 0·5 0·1 0·3 0·3 0·1						Sulphur dioxide	Not detected				23
									Copper		0·12 0·06 0·05 0·03 <0·01			
									Manganese		0·5 0·1 <0·1 (in four samples)			
									Inorganic fluoride		0·2 0·2 0·1 0·8 0·1			
		Not detected 9″ above weld 0·2 9″ above weld	0·4						Copper		<0·01			24
									Inorganic fluoride		0·2			
	Not detected		2·3											25
	Not detected		1·2 0·1 (different sampling points)						Hydrogen fluoride			Not detected		26
									Inorganic fluoride		1·0 0·1			

Appendix A (*continued*). Full results of survey

Reference	Type of welding or cutting	Type of elec-trode	Material	Surface treat-ment	Situa-tion	Ventila-tion	Carbon monoxide in ppm (TLV 50)			Carbon dioxide in ppm (TLV 5000)			Nitrogen dioxide in ppm (ceiling value 5)		
							In fume	Breathing level	Other samples	In fume	Breathing level	Other samples	In fume	Breathing level	Other samples
29	Carbon dioxide shielded arc welding	Mild steel wire	Mild steel	None	Shed. Open space	Natural ventilation	500 240 250		15 inside shield	60000 12000		7000 inside shield	0·5		
30	Submerged arc welding	Mild steel wire	Mild steel	Red oxide painted	Shed. Open space	Natural ventilation	300								
31	Oxy-propane cutting	—	Mild steel	Red oxide painted	Shed. Open space	Local exhaust ventilation									
32	Oxy-propane cutting	—	Mild steel	Zinc painted	Ship. Semi-confined space	Natural ventilation									
33	Open arc welding	Rutile type flux covered	Mild steel	Zinc painted	Ship. Semi-confined spaced	Forced general ventilation		10			1000			6·0 8·0 8·0	
34	Open arc welding	Rutile type flux covered	Mild steel	Zinc painted	Ship. Semi-confined space	Forced general ventilation		10						4·0 3·0	
35	Open arc welding	Rutile type flux covered	Mild steel	Zinc painted	Shed. Open space	Local exhaust ventilation									
36	Open arc welding	Rutile type flux covered	Mild steel	Zinc painted	Ship. Confined space	(a) Forced general ventilation	100			1000	1000 700		10·0	4·0 2·0	0·7 inside shield
						(b) Local exhaust ventilation									0·5 inside shield
37	Open arc welding	Rutile type flux covered	Mild steel	Zinc painted	Ship. Open air	Natural ventilation									
38	Oxy-acetylene cutting	—	Mild steel	Zinc painted	Ship. Confined space	Forced general ventilation	40	30			3000		12·0 12·0	10·0 8·0 9·0	10·0 10·0 9·0 4 ft above weld
39	Open arc welding	Rutile type flux covered	Mild steel	Zinc painted	Shed. Semi-confined space	Natural ventilation		6 5			400 400			1·5 1·0	
40	Open arc welding	Rutile type flux covered	Mild steel	Zinc painted	Shed. Open space	Natural ventilation									
41	Open arc welding	Rutile type flux covered	Mild steel	Zinc painted	Ship. Confined space	(a) Natural ventilation			100 6 ft from weld			6000 6 ft from weld			4·0 6 ft from weld
						(b) Forced general ventilation			60 3 ft from weld			2000 3 ft from weld			3·0 3 ft from weld
42	Air gouging	Carbon	Mild steel	Zinc painted	Ship. Open air	Natural ventilation		7 10 20						1·0 2·0 1·0	
43	Open arc welding	Rutile type flux covered	Mild steel	Zinc painted	Ship. Semi-confined space	Natural ventilation	80		10 inside shield	300			0·6 3·0		2·0 inside shield

Ozone in ppm (TLV 0·1)			Iron in mg./cu. m. (TLV 10)			Zinc in mg./cu. m. (TLV 5)			Other contaminants, where tested, listed with TLVs and units					
In fume	Breathing level	Other samples	General atmosphere	Breathing level	Personal respirometer	General atmosphere	Breathing level	Personal respirometer	Sulphur dioxide 5 ppm Hydrogen fluoride 3 ppm Aluminium No TLV mg./cu. m. Lead 0·2 mg./cu. m. Copper 0·1 mg./cu. m. Manganese (CV) 5 mg./cu. m. Nickel 1 mg./cu. m. Cobalt Tentative 0·1 mg./cu. m. Inorganic fluoride 2·5 mg./cu. m.	In fume	General atmosphere	Breathing level	Personal respirometer	Reference
1·7		Not detected inside shield							Sulphur dioxide	Not detected				29
														30
			1·2		9·2			Not detected						31
					10·0			Not detected						32
			3·1		7·4	5·7		Not detected						33
					3·4			Not detected						34
			2·5		3·5	Not detected		Not detected						35
Not detected			0·3 1·9 1·4	0·7 10·9 3·1	12·4 25·2 7·5 3·1	30·2 25·0 11·5	60·0 41·0 8·6	55·0 16·8 24·5 4·1 4·0	(During this test on a proprietary zinc-rich paint there were several different sampling points for two men in the space)					36
			1·5	1·3	15·2 <0·1	5·0	2·7	Not detected (two samples)						
			2·0 3·3	5·0 0·9		10·8 5·5	18·0 6·8							37
														38
			2·9 3·7		7·7 8·3 7·7	1·6 2·7		5·9 4·4 4·8	Sulphur dioxide			Not detected		39
									Inorganic fluoride		<0·1 <0·1		0·4 0·4 0·1	
			1·1 0·1			0·8 <0·1			Inorganic fluoride		<0·1 0·4			40
			16·8		53·0 60·0	6·5		16·7 17·0	Inorganic fluoride		0·8		1·0 1·0	41
			0·4		29·0 13·5	Not detected		4·9 2·8	Inorganic fluoride		0·4		0·6 0·1	
	Not detected		4·3		23·9	Not detected		<0·1	Inorganic fluoride		2·8		<0·1	42
			1·4		3·0	1·2		1·4	Inorganic fluoride		Not detected		<0·1	43

Appendix A (*continued*). **Full results of survey**

							Carbon monoxide in ppm (TLV 50)			Carbon dioxide in ppm (TLV 5000)			Nitrogen dioxide in ppm (ceiling value 5)		
Reference	Type of welding or cutting	Type of electrode	Material	Surface treatment	Situation	Ventilation	In fume	Breathing level	Other samples	In fume	Breathing level	Other samples	In fume	Breathing level	Other samples
44	Oxy-propane cutting	—	Mild steel	Zinc painted	Ship. Semi-confined space	Natural ventilation					900			2·0	
45	Oxy-propane cutting	—	Mild steel	Zinc painted	Ship. Confined space	Natural ventilation		15			3000			7·0 9·0 7·0	
46	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Semi-confined space	Natural ventilation		10 10			2000 1500			10·0 10·0	
47	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Shed. (a) Semi-confined space (b) Open space	Natural ventilation		10 50 40			500 500			2·0 2·0	0·5 0·5 both inside shield
48	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Semi-confined space	Forced general ventilation									
49	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Semi-confined space	Forced general ventilation		6					0·7	0·2	
50	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Semi-confined space	Natural ventilation	10			1000			4·0		
51	Oxy-acetylene cutting	—	Mild steel	Multi-coat paint system	Ship. Semi-confined space	Natural ventilation		9			700			18·0 15·0	
52	Open arc welding	Rutile type flux covered	Mild steel	Contaminated with oil	Ship. Confined space	Natural ventilation		15 18			800 800			20·0 20·0	
53	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Open air	Natural ventilation	2			300			1·0		
54	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Semi-confined space	Natural ventilation	15	10		1000	500		3·0	1·0	
55	Open arc welding	Rutile type flux covered	Mild steel	Multi-coat paint system	Ship. Semi-confined space	Natural ventilation		15			1000			2·0 1·0	
56	Open arc welding	Rutile type flux covered	Mild steel	Multi-coat paint system	Ship. Very large space	Natural ventilation	12	12		900	900		2·0	0·7	
57	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Semi-confined space	Forced general ventilation		7			400			1·5	

Ozone in ppm (TLV 0·1)			Iron in mg./cu. m. (TLV 10)			Zinc in mg./cu. m. (TLV 5)			Other contaminants, where tested, listed with TLVs and units					
In fume	Breathing level	Other samples	General atmosphere	Breathing level	Personal respirometer	General atmosphere	Breathing level	Personal respirometer	Sulphur dioxide 5 ppm Hydrogen fluoride 3 ppm Aluminium No TLV mg./cu. m. Lead 0·2 mg./cu. m. Copper 0·1 mg./cu. m. Manganese (CV) 5 mg./cu. m. Nickel 1 mg./cu. m. Cobalt Tentative 0·1 mg./cu. m. Inorganic fluoride 2·5 mg./cu. m.	In fume	General atmosphere	Breathing level	Personal respirometer	Reference
					9·2			3·2	Inorganic fluoride				Not detected	44
					16·0			1·9	Inorganic fluoride				0·6	45
			56·0 28·4		37·0	1·2 0·4		0·6	Inorganic fluoride		3·0 3·2		1·0	46
			0·6 0·5		4·7 26·8 (different operators)	<0·1 (three samples)		1·9 3·4	Inorganic fluoride		<0·1 0·3		0·6 0·9	47
			0·2			Not detected			Inorganic fluoride		0·4			
			1·8		2·6	Not detected		Not detected						48
			2·5		3·7	2·0		<0·1						49
Not detected			36·9 10·0		25·0	<0·1 0·6		0·2	Sulphur dioxide	Not detected				50
									Lead		0·1 <0·1		0·1	
	Not detected		9·4		4·4	1·5		0·1	Sulphur dioxide			Not detected		51
									Lead		Not detected		0·1	
	Not detected		23·3		32·4	Not detected		0·8	Sulphur dioxide			Not detected		52
									Lead		Not detected		0·1	
			0·9		1·6	0·3		1·6	Lead		Not detected		<0·1	53
Not detected			16·0		12·7			0·5	Sulphur dioxide	Not detected				54
			13·6		5·7	14·3		1·6	Lead		0·6		0·1	55
			0·5 1·2		6·5	<0·1 3·7 (different sampling points)		0·6	Lead		0·1 <0·1		Not detected	56
					3·8				Lead				Not detected	57

Appendix B. Open arc welding on zinc-coated mild steel

Reference	Type of welding or cutting	Type of electrode	Material	Surface treatment	Situation	Ventilation	Carbon monoxide in ppm (TLV 50)			Carbon dioxide in ppm (TLV 5000)			Nitrogen dioxide in ppm (ceiling value 5)		
							In fume	Breathing level	Other samples	In fume	Breathing level	Other samples	In fume	Breathing level	Other samples
1	Open arc welding	Rutile type flux covered	Mild steel	Zinc sprayed	Ship. Confined space	Forced general ventilation	4 6 40	5 12					4·0 7·0	1·5 0·7	
2	Open arc welding	Rutile type flux covered	Mild steel	Zinc sprayed	Ship. Semi-confined space	Forced general ventilation		5 5			800			1·0 1·7	
5	Open arc welding	Rutile type flux covered	Mild steel	Zinc sprayed and painted	Ship. Semi-confined space	Forced general ventilation		5			800			2·0	0·7 inside shield
7	Open arc welding	Rutile type flux covered	Mild steel	Zinc sprayed	Ship. Semi-confined space	Forced general ventilation		5	Not detected 5 mins after welding ceased		500	800 5 mins after welding ceased	2·0 2·0 2·0	1·0	0·5 5 mins after and not detected 10 mins after welding ceased
9	Open arc welding	Rutile type flux covered	Mild steel	Galvanised	Shed. Open space	Natural ventilation		10			600		8·0	6·0	0·5 inside shield
33	Open arc welding	Rutile type flux covered	Mild steel	Zinc painted	Ship. Semi-confined space	Forced general ventilation		10			1000			6·0 8·0 8·0	
34	Open arc welding	Rutile type flux covered	Mild steel	Zinc painted	Ship. Semi-confined space	Forced general ventilation		10						4·0 3·0	
35	Open arc welding	Rutile type flux covered	Mild steel	Zinc painted	Shed. Open space	Local exhaust ventilation									
36	Open arc welding	Rutile type flux covered	Mild steel	Zinc painted	Ship. Confined space	(a) Forced general ventilation	100			1000	1000 700		10·0	4·0 2·0	0·7 inside shield
						(b) Local exhaust ventilation									0·5 inside shield
37	Open arc welding	Rutile type flux covered	Mild steel	Zinc painted	Ship. Open air	Natural ventilation									
39	Open arc welding	Rutile type flux covered	Mild steel	Zinc painted	Shed. Semi-confined space	Natural ventilation		6 5			400 400			1·5 1·0	
40	Open arc welding	Rutile type flux covered	Mild steel	Zinc painted	Shed. Open space	Natural ventilation									
41	Open arc welding	Rutile type flux covered	Mild steel	Zinc painted	Ship. Confined space	(a) Natural ventilation			100 6 ft from weld			6000 6 ft from weld			4·0 6 ft from weld
						(b) Forced general ventilation			60 3 ft from weld			2000 3 ft from weld			3·0 3 ft from weld
43	Open arc welding	Rutile type flux covered	Mild steel	Zinc painted	Ship. Semi-confined space	Natural ventilation	80		10 inside shield	300			0·6 3·0		2·0 shield inside

Ozone in ppm (TLV 0·1)			Iron in mg./cu. m. (TLV 10)			Zinc in mg./cu. m. (TLV 5)			Other contaminants, where tested, listed with TLVs and units					
In fume	Breathing level	Other samples	General atmosphere	Breathing level	Personal respirometer	General atmosphere	Breathing level	Personal respirometer	Sulphur dioxide 5 ppm Inorganic fluoride 2·5 mg./cu. m.	In fume	General atmosphere	Breathing level	Personal respirometer	Reference
Not detected	Not detected		2·1						Sulphur dioxide	Not detected				1
					Not detected			Not detected	Sulphur dioxide	Not detected				2
	Not detected		<0·1 0·4		5·0	86 271		11·0	Sulphur dioxide			Not detected		5
	Not detected		0·6		1·7	720		47	Sulphur dioxide			Not detected		7
	Not detected		0·1 0·8	13·3	0·3	17·8 11·6	168	Not detected	Sulphur dioxide	Not detected				9
			3·1		7·4	5·7		Not detected						33
					3·4			Not detected						34
			2·5		3·5	Not detected		Not detected						35
Not detected			0·3 1·9 1·4	0·7 10·9 3·1	12·4 25·2 7·5 3·1	30·2 25·0 11·5	60·0 41·0 8·6	55·0 16·8 24·5 4·1 4·0	(During this test on a proprietary zinc-rich paint there were several different sampling points for two men in the space)					36
			1·5	1·3	15·2 <0·1	5·0	2·7	Not detected (two samples)						
			2·0 3·3	5·0 0·9		10·8 5·5	18·0 6·8							37
			2·9 3·7		7·7 8·3 7·7	1·6 2·7		5·9 4·4 4·8	Sulphur dioxide			Not detected		39
									Inorganic fluoride		<0·1 <0·1		0·4 0·4 0·1	
			1·1 0·1			0·8 <0·1			Inorganic fluoride		<0·1 0·4			40
			16·8		53·0 60·0	6·5		16·7 17·0	Inorganic fluoride		0·8		1·0 1·0	41
			0·4		29·0 13·5	Not detected		4·9 2·8	Inorganic fluoride		0·4		0·6 0·1	
			1·4		3·0	1·2		1·4	Inorganic fluoride		Not detected		<0·1	43

Appendix C. Open arc welding on mild steel not coated with zinc

Reference	Type of welding or cutting	Type of electrode	Material	Surface treatment	Situation	Ventilation	Carbon monoxide in ppm (TLV 50)			Carbon dioxide in ppm (TLV 5000)			Nitrogen dioxide in ppm (ceiling value 5)		
							In fume	Breathing level	Other samples	In fume	Breathing level	Other samples	In fume	Breathing level	Other samples
3	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Confined space	Forced general ventilation		5			1000			1·0	
8	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Semi-confined space	Forced general ventilation		5			1000		2·0 5·0	0·5	
11	Open arc welding	Basic coated low hydrogen electrode	Mild steel	Red oxide painted	Shed. Open space	Natural ventilation	25	Not detected		2000			6·0	Not detected	
15	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Confined space	Natural ventilation		10 20 25 30			1400 2000 2100 2200			4·0 4·0 5·0 8·0 10·0	
16	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Confined space	Natural ventilation		7 10 10 10 10			1500 1000 1000 1000 1000			4·0 4·0 6·0 4·0 3·0	
23	Open arc welding	Basic coated low hydrogen electrode	Special grade man-ganese steel	Red oxide painted	Ship. Very large space	Forced general ventilation	120	7		600	400		1·5	0·7	
24	Open arc welding	Basic coated low hydrogen electrode	Special grade man-ganese steel	Red oxide painted	Ship. Very large space	(a) Local exhaust ventilation (b) Natural ventilation			Not detected 9″ above weld 50 9″ above weld			300 9″ above weld 1500 9″ above weld			Not detected. 9″ above weld 5·0 9″ above weld
25	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Shed. Semi-confined space	Natural ventilation		20	6 inside shield		1200	5000 inside shield	4·0	1·5	0·8 5 ft. above weld
26	Open arc welding	Basic coated low hydrogen electrode	Mild steel	Red oxide painted	Shed. Open space	Natural ventilation		10			1000			1·0	
46	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Semi-confined space	Natural ventilation		10 10			2000 1500			10·0 10·0	
47	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Shed. (a) Semi-confined space (b) Open space	Natural ventilation		10 50 40			500 500			2·0 2·0	0·5 0·5 both inside shield

Ozone in ppm (TLV 0·1)			Iron in mg./cu. m. (TLV 10)			Zinc in mg./cu. m. (TLV 5)			Other contaminants, where tested, listed with TLVs and units					
In fume	Breathing level	Other samples	General atmosphere	Breathing level	Personal respirometer	General atmosphere	Breathing level	Personal respirometer	Sulphur dioxide 5 ppm Hydrogen fluoride 3 ppm Lead 0·2 mg./cu. m. Copper 0·1 mg./cu. m. Manganese (CV) 5 mg./cu. m. Inorganic fluoride 2·5 mg./cu. m.	In fume	General atmosphere	Breathing level	Personal respirometer	Reference
Not detected			1·5						Sulphur dioxide	Not detected				5
	Not detected		7·5 0·4 (different sampling points)		0·2	1·1 0·2 (different sampling points)		Not detected	Sulphur dioxide			Not detected		8
									Hydrogen fluoride			Not detected		
									Inorganic fluoride		0·3 & Not detected		Not detected	
Not detected			1·9 (28·4 in fume)		0·1				Sulphur dioxide	Not detected				11
									Hydrogen fluoride	Not detected				
									Inorganic fluoride	42·0	<0·1 <0·1		0·8	
														15
														16
0·15 0·12			0·7 0·5 0·1 0·3 0·3 0·1						Sulphur dioxide	Not detected				23
									Copper		0·12 0·06 0·05 0·03 <0·01			
									Manganese		0·5 0·1 <0·1 (four samples)			
									Inorganic fluoride		0·2 0·2 0·1 0·8 0·1			
		Not detected 9″ above weld 0·2 9″ above weld	0·4						Copper		<0·1			24
									Inorganic fluoride		0·2			
	Not detected		2·3											25
	Not detected		1·2 0·1 (different sampling points)						Hydrogen fluoride			Not detected		26
									Inorganic fluoride		1·0 0·1			
			56·0 28·4		37·0	1·2 0·4		0·6	Inorganic fluoride		3·0 3·2		1·0	46
			0·6 0·5		4·7 26·8 (different operators)	<0·1 three samples		1·9 3·4	Inorganic fluoride		<0·1 0·3		0·6 0·9	47
			0·2			Not detected			Inorganic fluoride		0·4			

Appendix C (*continued*). Open arc welding on mild steel not coated with zinc

Reference	Type of welding or cutting	Type of electrode	Material	Surface treatment	Situation	Ventilation	Carbon monoxide in ppm (TLV 50)			Carbon dioxide in ppm (TLV 5000)			Nitrogen dioxide in ppm (ceiling value 5)		
							In fume	Breathing level	Other samples	In fume	Breathing level	Other samples	In fume	Breathing level	Other samples
48	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Semi-confined space	Forced general ventilation									
49	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Semi-confined space	Forced general ventilation		6					0·7	0·2	
50	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Semi-confined space	Natural ventilation	10			1000			4·0		
52	Open arc welding	Rutile type flux covered	Mild steel	Contaminated with oil	Ship. Confined space	Natural ventilation		15 18			800 800			20·0 20·0	
53	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Open air	Natural ventilation	2			300			1·0		
54	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Semi-confined space	Natural ventilation	15	10		1000	500		3·0	1·0	
57	Open arc welding	Rutile type flux covered	Mild steel	Red oxide painted	Ship. Semi-confined space	Forced ventilation		7			400			1·5	

Ozone in ppm (TLV 0·1)			Iron in mg./cu. m. (TLV 10)			Zinc in mg./cu. m. (TLV 5)			Other contaminants, where tested, listed with TLVs and units					
In fume	Breathing level	Other samples	General atmosphere	Breathing level	Personal respirometer	General atmosphere	Breathing level	Personal respirometer	Sulphur dioxide 5 ppm Hydrogen fluoride 3 ppm Lead 0·2 mg./cu. m. Copper 0·1 mg./cu. m. Manganese (CV) 5 mg./cu. m. Inorganic fluoride 2·5 mg./cu. m.	In fume	General atmosphere	Breathing level	Personal respirometer	Reference
			1·8		2·6	Not detected		Not detected						48
			2·5		3·7	2·0		<0·1						49
Not detected			36·9 10·0		25·0	<0·1 0·6		0·2	Sulphur dioxide	Not detected				50
									Lead		0·1 <0·1		0·1	
	Not detected		23·3		32·4	Not detected		0·8	Sulphur dioxide			Not detected		52
									Lead		Not Detected		0·1	
			0·9		1·6	0·3		1·6	Lead		Not detected		<0·1	53
Not detected			16·0		12·7			0·5	Sulphur dioxide	Not detected				54
					3·8				Lead				Not detected	57

Appendix D. Gas-shielded welding on various materials

							Carbon monoxide in ppm (TLV 50)			**Carbon dioxide in ppm (TLV 5000)**			**Nitrogen dioxide in ppm (ceiling value 5)**		
Reference	**Type of welding or cutting**	**Type of electrode**	**Material**	**Surface treatment**	**Situation**	**Ventilation**	In fume	Breathing level	Other samples	In fume	Breathing level	Other samples	In fume	Breathing level	Other samples
10	Argon and carbon dioxide shielded arc welding	Copper coated mild steel wire	Mild steel	None	Shed. Open space	Local exhaust ventilation		15			1700			0·6	
13	Argon and carbon dioxide shielded arc welding	Copper coated mild steel wire	Mild steel	None	Shed. Open space	Natural ventilation							0·3 5·0		
29	Carbon dioxide shielded arc welding	Mild steel wire	Mild steel	None	Shed. Open space	Natural ventilation	500 240 250		15 inside shield	60000 120000		7000 inside shield	0·5		
4	Argon shielded arc welding	Stainless steel wire	Stainless steel	None	Ship. Semi-confined space	Natural ventilation		Not detected			200			4·0	1·0 inside shield
12	Argon shielded arc welding	Stainless steel wire	Stainless steel	None	Shed. Open space	Natural ventilation	Not detected			600			1·0 0·4	Not detected	
19	Carbon dioxide shielded arc welding	Copper coated steel wire	Special grade manganese steel	Red oxide painted	Shed. Open space	Natural ventilation	200 200			5500			0·3 <0·1		
6	Argon shielded arc welding	Aluminium wire	Aluminium	None	Shed. Open space	Natural ventilation		<5			200			5·0	0·5 inside shield
14	Argon shielded arc welding	Aluminium wire	Aluminium	None	Shed. Confined space	Natural ventilation	Not detected			600			1·0 1·5		
21	Argon shielded arc welding	Aluminium wire	Aluminium	None	Shed. Open space	Natural ventilation		Not detected			500			4·0 5·0 0·7	

Ozone in ppm (TLV 0·1)			Iron in mg./cu. m. (TLV 10)			Zinc in mg./cu. m. (TLV 5)			Other contaminants, where tested, listed with TLVs and units					
In fume	Breathing level	Other samples	General atmosphere	Breathing level	Personal respirometer	General atmosphere	Breathing level	Personal respirometer	Sulphur dioxide 5 ppm Aluminium No TLV mg./cu. m. Lead 0·2 mg./cu. m. Copper 0·1 mg./cu. m. Manganese (CV) 5 mg./cu. m. Nickel 1 mg./cu. m. Cobalt (tentative) 0·1 mg./cu. m.	In fume	General atmosphere	Breathing level	Personal respirometer	Reference
1·6	0·7	Not detected inside shield	1·3		6·7	Not detected		Not detected	Sulphur dioxide			Not detected		10
									Lead (different results from different sampling points)		<0·1 1·0		Not detected	
									Copper		0·02 1·4		0·03	
0·9 0·05 (different sampling points)														13
1·7		Not detected inside shield							Sulphur dioxide	Not detected				29
	0·09		0·7		5·5	<0·1		<0·1	Sulphur dioxide			Not detected		4
									Manganese		<0·1		0·2	
									Nickel		<0·1		0·1	
									Cobalt		<0·01		Not detected	
1·0 0·05 (different sampling points)	Not detected		<0·1 0·3		11·3				Sulphur dioxide	Not detected				12
									Manganese		<0·1 <0·1		<0·1	
									Nickel		<0·1 <0·1		<0·1	
									Cobalt		Not detected		Not detected	
0·1 <0·1			6·2	10·0					Sulphur dioxide	Not detected				19
									Lead		0·1 <0·1	0·7		
									Copper		<0·1 0·5	0·8		
									Manganese		0·1 0·1	1·7		
	<0·01		<0·1			2·0		<0·1						6
0·2 0·3									Sulphur dioxide	Not detected				14
									Aluminium	3·1				
	0·9 0·6 0·9													21

Appendix E. Submerged arc welding on various materials

							Carbon monoxide in ppm (TLV 50)			**Carbon dioxide in ppm (TLV 5000)**			**Nitrogen dioxide in ppm (ceiling value 5)**		
Reference	**Type of welding or cutting**	**Type of electrode**	**Material**	**Surface treatment**	**Situation**	**Ventilation**	In fume	Breathing level	Other samples	In fume	Breathing level	Other samples	In fume	Breathing level	Other samples
18	Submerged arc welding	Copper coated mild steel wire	Mild steel	Red oxide painted	Shed. Open space	Natural ventilation	1000 750	15 30		500			Not detected		
20	Submerged arc welding	Copper coated mild steel wire	Mild steel	Red oxide painted	Shed. Open space	Natural ventilation	340	Not detected	40 12″ above weld	300			Not detected		
22	Submerged arc welding	Copper coated steel wire	Special grade manganese steel	Red oxide painted	Shed. Open space	Natural ventilation	300	Not detected	50 12″ above	400			0·3		
30	Submerged arc welding	Mild steel wire	Mild steel	Red oxide painted	Shed. Open space	Natural ventilation	300								

Ozone in ppm (TLV 0·1)			Iron in mg./cu. m. (TLV 10)			Zinc in mg./cu. m. (TLV 5)			Other contaminants, where tested, listed with TLVs and units					
In fume	Breathing level	Other samples	General atmosphere	Breathing level	Personal respirometer	General atmosphere	Breathing level	Personal respirometer	Sulphur dioxide 5 ppm Hydrogen fluoride 3 ppm Lead 0·2 mg./cu. m. Copper 0·1 mg./cu. m. Inorganic fluoride 2·5 mg./cu. m.	In fume	General atmosphere	Breathing level	Personal respirometer	Reference
Not detected			— (4·2 in fume)						Sulphur dioxide	Not detected				18
									Lead	1·4				
									Copper	0·3				
									Inorganic fluoride	8·3				
									Hydrogen fluoride	Not detected				20
														22
														30

Appendix F. Gas cutting on mild steel

							Carbon monoxide in ppm (TLV 50)			Carbon dioxide in ppm (TLV 5000)			Nitrogen dioxide in ppm (ceiling value 5)		
Reference	Type of welding or cutting	Type of electrode	Material	Surface treatment	Situation	Ventilation	In fume	Breathing level	Other samples	In fume	Breathing level	Other samples	In fume	Breathing level	Other samples
31	Oxy-propane cutting	—	Mild steel	Red oxide painted	Shed. Open space	Local exhaust ventilation									
32	Oxy-propane cutting	—	Mild steel	Zinc painted	Ship. Semi-confined space	Natural ventilation									
38	Oxy-acetylene cutting	—	Mild steel	Zinc painted	Ship. Confined space	Forced general ventilation	40	30			3000		12·0 12·0	10·0 8·0 9·0	10·0 10·0 9·0 4 ft above weld
44	Oxy-propane cutting	—	Mild steel	Zinc painted	Ship. Semi-confined space	Natural ventilation					900			2·0	
45	Oxy-propane cutting	—	Mild steel	Zinc painted	Ship. Confined space	Natural ventilation		15			3000			7·0 9·0 7·0	
51	Oxy-acetylene cutting	—	Mild steel	Multi-coat paint system	Ship. Semi-confined space	Natural ventilation		9			700			18·0 15·0	

Ozone in ppm (TLV 0·1)			Iron in mg./cu. m. (TLV 10)			Zinc in mg./cu. m. (TLV 5)			Other contaminants, where tested, listed with TLVs and units					
In fume	Breathing level	Other samples	General atmosphere	Breathing level	Personal respirometer	General atmosphere	Breathing level	Personal respirometer	Sulphur dioxide 5 ppm Lead 0·2 mg./cu. m. Inorganic fluoride 2·5 mg./cu. m.	In fume	General atmosphere	Breathing level	Personal respirometer	Reference
			1·2		9·2			Not detected						31
					10·0			Not detected						32
														38
					9·2			3·2	Inorganic fluoride				Not detected	44
					16·0			1·9	Inorganic fluoride				0·6	45
	Not detected		9·4		4·4	1·5		0·1	Sulphur dioxide			Not detected		51
									Lead		Not detected		0·1	

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